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## Heat Transmission in Rotary Kilns.—VI.

By W. GILBERT, Wh.Sc., M.Inst.C.E.

(109) It is now proposed to examine the heat transmission in a modern rotary kiln working on the wet process, the length being approximately 400 ft. The kiln is generally 9 ft. 4½ in. in diameter inside the shell plates, with an enlarged zone 11 ft. 4 in. in diameter. The cooler tubes are arranged around the delivery end of the kiln.

In daily work the clinker output is 15½ tons per hour, with a standard coal consumption of 24.5 per cent. The slurry contains 42.5 per cent. of moisture. By the aid of chains the waste-gas temperature, as measured by a pyrometer shielded from radiation loss, is reduced to 500 deg. F. The coal is dried and ground in a pulveriser of the ring roll type to a residue of 35.5 per cent. on the 170-mesh sieve.

A longitudinal section of the kiln drawn to an enlarged vertical scale is shown in Fig. 19. At the slurry end there are 648 chains, each 9 ft. 6 in. long, of ¾ in. diameter round iron. The chains commence 16 ft. from the feed end of the kiln, and extend for a distance of 96 ft. At the delivery end there is a firebrick ring through which the clinker is delivered to the openings in the kiln shell which feed the cooler tubes. From the inside of the firebrick ring at (4), to the feed end of the kiln the length available for heat transmission is 385 ft.

(110) The various stages used in the heat transmission calculations are shown on Fig. 19. In stage (1) the temperature of the slurry is raised from 60 deg. to 212 deg. F. In each of stages (2), (3), (4) and (5), one-fourth of the slurry moisture is evaporated. In stages (6) to (9) the material temperature is raised from 212 deg. to 1,500 deg. F. In stages (10) and (11) the CaCO<sub>3</sub> is decomposed, the material temperature rising to 1,700 deg. F. In stage (12) the material temperature is raised from 1,700 deg. to 1,850 deg. F. In stage (13) the material temperature is finally raised from 1,850 deg. to 2,450 deg. F. by the exothermic reaction, and clinkering takes place. Stage (14) is the dead end of the kiln.

It will be seen that the chains are mainly employed in raising the temperature of the slurry and in evaporating the first quarter of the moisture. Without the chains the kiln shell would have to be lengthened a further 207 ft. in order to obtain the same result.

(xi) Various particulars relating to the working of the kiln which will be required for calculation purposes are as follows:

(a)	Clinker per minute	..	..	..	..	..	578.5 lb.
(b)	Dry coal, as fired, per minute	..	..	..	..	..	156.4 lb.
(c)	Dry coal as fired per 100 lb. of clinker	..	..	..	..	..	27.05 lb.
(d)	Coal calorific value, B.T.U. per pound	..	..	..	..	..	11,415
(e)	Standard coal used per 100 lb. of clinker	..	..	..	..	..	24.50 lb.
(f)	Air required per pound of coal (net)	..	..	..	..	..	8.70 lb.
(g)	Excess air used	..	..	..	..	..	10.30 per cent.
(h)	Slurry moisture per 100 lb. of clinker	..	..	..	..	..	112.0 lb.
(i)	$\text{CaCO}_3$ per 100 lb. of clinker	..	..	..	..	..	117.0 lb.
(j)	$\text{CO}_2$ from raw material per 100 lb. of clinker	..	..	..	..	..	51.6 lb.
(k)	Temperature of kiln exit gases	..	..	..	..	..	500 deg. F.
(l)	Slope of kiln	..	..	..	..	..	1 in 25
(m)	Speed of kiln	..	..	..	..	..	1 R.P.M.

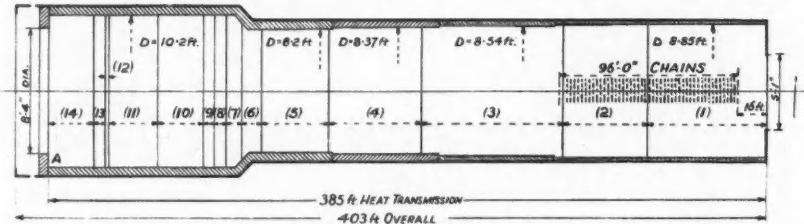


Fig. 19.

(ii) COAL ANALYSIS.—The dry coal as fired (on the average) consisted of carbon 64.23 per cent., hydrogen 4.74 per cent., sulphur 1.23 per cent., oxygen 9.07 per cent., nitrogen 1.18 per cent., and ash 19.55 per cent.

From the coal analysis, the weight of the products of combustion, per pound of dry coal, can be obtained (see CEMENT AND CEMENT MANUFACTURE, November, 1930, p. 1472). The two last items in the following table are obtained from (para. iii (c), (h) and (j)).

#### WEIGHT OF KILN GASES PER POUND OF DRY COAL AS FIRED.

	lb.
$\text{CO}_2$ from combustion	2.36
$\text{H}_2\text{O}$	0.45
$\text{N}_2$	6.67
Excess air	0.90
$\text{CO}_2$ from raw material	1.91
Steam from slurry	4.14
Total	16.43

(iii) The heat content of the kiln gases at various temperatures is next obtained by the method described in Part IV, paras. 76 to 79 (CEMENT AND CEMENT MANUFACTURE, August, 1933). A heat expenditure of 1 lb. of standard coal per 100 lb. of clinker is here equivalent to  $\frac{12,600}{27.05}$  or 466 B.T.U. per pound of dry coal as fired.

TABLE XVII.

HEAT CONTENT ABOVE 60 DEG. F. OF THE KILN GASES AT VARIOUS TEMPERATURES  
EXPRESSED IN LB. OF STANDARD COAL PER 100 LB. OF CLINKER.

	Gas Temperatures in Deg. F.				
	500	1,000	1,500	2,000	2,450
Products of combustion ..	3.48	6.34	9.32	12.44	15.29
CO <sub>2</sub> from raw material ..	0.38	0.87	1.38	1.95	2.47
Steam from slurry ..	11.22	13.32	15.58	17.97	20.36

(114) The heat balances for the kiln and cooler are next obtained, substantially by the method described in this Journal for November, 1930, p. 1479.

## HEAT BALANCE FOR KILN.

	Standard coal per cent. on clinker.
(a) Decomposition of CaCO <sub>3</sub> ..	7.24
(b) Evaporation and superheat of slurry moisture ..	11.22
(c) Loss in products of combustion and in excess air at 500 deg. F. ..	3.48
(d) Loss in CO <sub>2</sub> from raw material at 500 deg. F. ..	0.38
(e) Radiation loss from kiln ..	2.11
(f) Radiation loss from cooler ..	0.35
(g) Hot clinker loss at cooler delivery end ..	0.77
(h) Allowance for heat spent in coal drying ..	0.30
	25.85
Allow for exothermic reaction ..	1.35
Total used by kiln ..	24.50

## (115) HEAT BALANCE FOR COOLER.

	Standard coal per cent. on clinker.
(a) Radiation and hot clinker loss ..	1.12
(b) Radiation loss in kiln dead end ..	0.28
(c) Hot air supplied for coal drying ..	0.30
(d) Hot air supplied to kiln ..	3.20

Heat given up by clinker range 2,450 deg. F. - 60 deg. F.  $\phi = 0.258$  4.90

(116) REARRANGEMENT OF KILN HEAT BALANCE.—The heat quantities are now rearranged (see next page) in order to show in proper order the heat which has to be transmitted to the material in the various stages as it travels down the kiln. The calculations are based on 100 lb. of clinker. Specific heat is denoted by  $\phi$ . Paras. (81) and (82) in Part IV should be again read in this connection.

## Details of the Heat Supply.

(117) As the coal particles burn in the combustion zone at a temperature of 2,450 deg. F., part of the heat developed is radiated from the surface of the incandescent particles and the remainder is used to raise the temperature of the products of combustion and the CO<sub>2</sub> from the raw material. These gases are

		Standard coal. (lb.).
(a) <i>Evaporation of Slurry Moisture—</i>		
100 lb. of raw material raised from 60 deg. to 212 deg. F. ( $\phi = 0.25$ ) .. . . . .	0.30	
51.6 lb. of $\text{CO}_2$ (incorporated) raised from 60 deg. to 212 deg. F. ( $\phi = 0.21$ ) .. . . . .	0.13	
112 lb. of water raised from 60 deg. to 212 deg. F. .. . . .	1.35	
112 lb. of water evaporated from and at 212 deg. F. (latent heat = 970) .. . . . .	8.63	
112 lb. steam superheated to 500 deg. F. .. . . . .	1.24	
Radiation from kiln shell .. . . . .	0.74	
(b) <i>Raising Raw Material Temperature—</i>		12.39
100 lb. of raw material raised from 212 deg. to 1,300 deg. F. ( $\phi = 0.25$ ) .. . . . .	2.16	
51.6 lb. of $\text{CO}_2$ (incorporated) raised from 212 deg. to 1,300 deg. F. ( $\phi = 0.234$ ) .. . . . .	1.04	
Radiation from kiln shell .. . . . .	0.23	
(c) <i>Decomposition of <math>\text{CaCO}_3</math>—</i>		3.43
100 lb. of raw material raised from 1,300 deg. to 1,500 deg. F. ( $\phi = 0.25$ ) .. . . . .	0.79	
51.6 lb. of $\text{CO}_2$ (incorporated) raised from 1,300 deg. to 1,500 deg. F. ( $\phi = 0.257$ ) .. . . . .	0.21	
Decomposition of 117 lb. of $\text{CaCO}_3$ .. . . . .	7.24	
Radiation from kiln shell .. . . . .	0.59	
(d) <i>Raising Material Temperature and Clinkering—</i>		8.83
100 lb. of material raised from 1,700 deg. to 1,850 deg. F. ( $\phi = 0.255$ ) .. . . . .	0.30	
100 lb. of material raised from 1,850 deg. to 2,450 deg. F. by the exothermic reaction ( $\phi = 0.284$ ) .. . . . .	1.35	
Radiation from kiln shell .. . . . .	0.12	
(e) <i>The Kiln Dead End—</i>		1.77
Heat supplied to the dead end by flame radiation (as shown later) .. . . . .	0.15	
	<b>Total</b> .. . . . .	<b>26.57</b>

assumed to reach a common temperature of 2,450 deg. F. when combustion is complete. The proportion of the total heat which is radiated is calculated as follows:

	Standard coal per cent. on clinker.
Heat is supplied to the combustion zone	
(a) By the coal as fired (see para. III, e) .. .. ..	24.50
(b) By air preheated (see Cooler Heat Balance) .. ..	3.20
Total .. .. ..	<u>27.70</u>
The above heat is expended as shown below :	
(c) In raising the temperature of the gaseous products of combustion from 60 deg. to 2,450 deg. F. (see Table XVII) ..	15.29
(d) In raising the temperature of the CO <sub>2</sub> from the raw material from 1,500 deg. F. to 2,450 deg. F. (see Table XVII) ..	1.09
(e) In heat radiated from the burning coke particles, which is by difference .. .. ..	<u>11.32</u>
Total .. .. ..	<u>27.70</u>

(118) It should be noticed that the CO<sub>2</sub> incorporated with the raw material is heated with it up to an average temperature of 1,500 deg. F. and the gas then formed is further raised to a temperature of 2,450 deg. F. by mixture with the other gases in the combustion zone of the kiln. It is then available for heat

transmission, in the zone of gas radiation and convection, throughout the temperature range 2,450 deg. to 500 deg. F.

The sources from which heat is transmitted to the material inside the kiln are therefore as follows :

					Per cent.
(a)	By radiation from the coke particles	..	..	..	11.32
(b)	By the exothermic reaction (standard value)	..	..	..	1.35
(c)	By the heat liberated from the products of combustion, and the CO <sub>2</sub> from the raw material, falling from 2,450 deg. to 500 deg. F. (see Table XVII) :	1.5.29 - 3.48 + 2.47 - 0.38	..	..	13.90
					26.57

This compares with the total in para. (116).

#### Heat Transmitted by Gas Radiation and Convection.

(119) The heat available by para. 118 (c) is 13.90 per cent. The heat required for stages (1) to (5), see para. 116 (a) is 12.39 per cent. The remainder (1.51 per cent.) is sufficient to raise the temperature of the dry raw material and the CO<sub>2</sub> incorporated from 212 deg. F. to 690 deg. F., which is done in stages (6) and (7).

The heat required in each of the stages (1) to (7) is now set down in Table XVIII by the aid of figures taken from para. 116. In stage (3), for instance, the heat supplied for evaporation and superheat is  $\frac{8.63}{4} + \frac{1.24}{4} = 2.47$  per cent. as shown in col. (2), and to this the shell radiation loss is added.

TABLE XVIII.

Stage No. (1)	Heat supplied per cent.			Gas composition at end of stage deg. F. (5)	Gas temperature at end of stage deg. F. (6)	Material temperature at end of stage deg. F. (7)
	To material. (2)	Shell* radiation. (3)	Total to end of stage considered. (4)			
1	1.78	0.06	1.84	P + C + S	674	212
2	2.47	0.08	4.39	P + C + $\frac{1}{2}$ S	948	212
3	2.47	0.20	7.06	P + C + $\frac{1}{2}$ S	1,296	212
4	2.47	0.20	9.73	P + C + $\frac{1}{2}$ S	1,736	212
5	2.46	0.20	12.39	P + C	2,250	212
6	0.70	0.05	13.14	P + C	2,350	451
7	0.71	0.05	13.90	P + C	2,450	690

(120) The heat which the gas must contain at the end of each stage reckoned above 500 deg. F. is set down in col. (4) and the gas composition is given in col. (5). For instance, at the end of stage (3) the gas consists of the products of combustion (P), the CO<sub>2</sub> from the raw material (C), and one-half of the steam from the slurry.

To obtain the gas temperature at the end of each stage a graph based on Table XVII is drawn (see Fig. 20) giving the total heat of the various gases

reckoned above the exit gas temperature of 500 deg. F. For instance, at the end of stage (3) the heat present in the gas should be 7.06 per cent., and from the line on the graph marked  $P + C + \frac{1}{4}S$  the required gas temperature is seen to be 1,296 deg. F.

In the calculations relating to the 200-ft. kiln the shell radiation loss was taken at 0.068 of the heat supplied to the material in each stage. In the kiln under consideration, however, most of the heat in stages (1) and (2) is transmitted by the chains, and the heat so transferred does not add to the shell radiation. Hence the latter has been calculated independently for stages (1) to (5), and the result

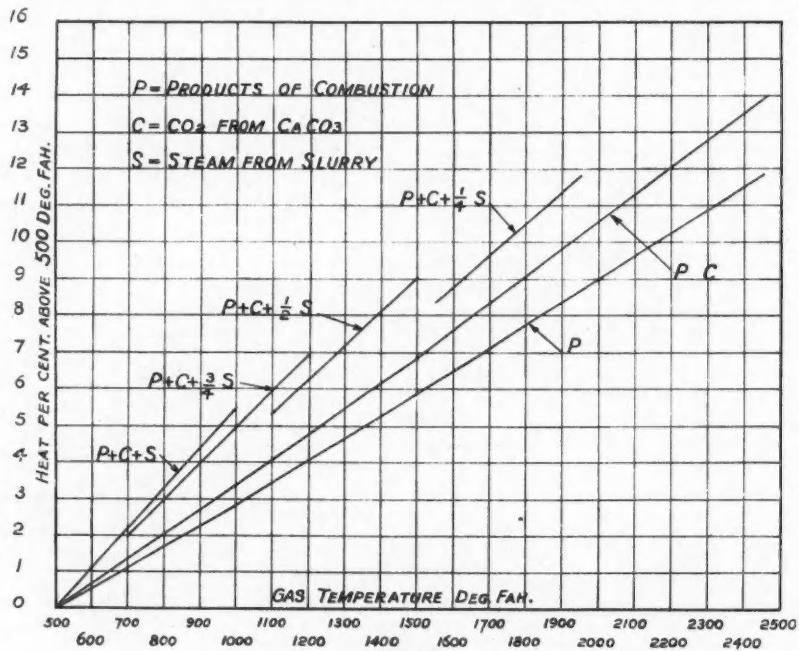


Fig. 20

is given in col. (3) of Table XVIII. For the remainder of the kiln the shell radiation loss is substantially one-fourteenth of the heat given to the material in each stage.

#### Preliminary Data for Stages (1) to (7).

(121) Various figures which will be useful later are set down in Table XIX. The method of obtaining them has been described generally in Part IV in connection with a 200-ft. kiln. Referring to line 1 of Table XIX, the kiln gases which occur in stage (1) are shown in detail in para. (112). The gases in the remaining stages are the same, except that one-fourth of the slurry moisture is eliminated in each of the stages (2) to (5).

TABLE XIX.  
PRELIMINARY DATA FOR STAGES (1) TO (7).  
(The figures given are average values for each Stage.)

Line No.		STAGE NUMBERS.						
		(1)	(2)	(3)	(4)	(5)	(6)	(7)
1	KILN GASES. Average weight per pound of dry coal as fired	16.43	15.91	14.87	13.84	12.81	12.29	12.29
2	Volume of kiln gases per pound of dry coal in cubic feet at 32 deg. F.	CO <sub>2</sub> H <sub>2</sub> O Total	34.80 91.36 222.5	34.80 81.00 212.1	34.80 60.30 191.4	34.80 39.80 170.9	34.80 19.30 150.4	34.80 9.00 140.1
5	Kiln diameter inside lining ft.	8.85	8.85	8.54	8.37	8.20	8.20	9.00
6	Kiln, area of cross section sq. ft.	61.5	61.5	57.3	55.0	52.8	52.8	63.6
7	Gas per hour per sq. ft. of cross section lb.	2,508	2,430	2,436	2,360	2,280	2,180	1,810
8	Average gas temperature in stage, deg. F. . . .	474	548	615	685	750	785	812
9	Gas volume per pound of coal at stage temperature cu. ft.	20.1	23.3	28.0	32.5	37.0	38.8	33.3
10	Gas velocity feet per second	2.04	1.99	1.98	1.94	1.87	1.80	1.55
11	Convection (a) Gas and lining	2.08	2.06	2.15	2.18	2.23	2.14	1.80
12	Constant Hc (b) Gas and material	3.63	3.38	2.69	1.95	1.05	0.53	0.58
13	Values of (a) for H <sub>2</sub> O	1.38	1.45	1.55	1.70	1.90	2.04	2.23
14	PD (b) for CO <sub>2</sub>	8.0	8.0	6.0	6.0	6.0	6.0	6.0
15	Charge in kiln . . . per cent.	21.18	21.18	21.05	20.64	20.23	20.23	22.20
16	Length of upper lining arc ft.	6.62	6.62	5.78	5.66	5.53	5.53	6.07
17	Length of lower lining arc ft.	6.00	6.00	5.34	5.24	5.12	5.12	5.63
18	Length of material chord . . ft.							

(122) The charge in the kiln (see line 15) is taken at 8 per cent. in stages (1) and (2) where the chains occur and at 6 per cent. in the remaining stages.

At the end of stage (6), see Fig. 19, the charge passes into the enlarged zone of the kiln, where the increase in diameter and in the rate of advance per revolution should reduce it to about 3 per cent. until the effect of the contracted outlet is felt. On inspection, however, it appeared that the inner surface of the lining of this part of the kiln was irregular, due probably to deposits of coal ash; hence the rate of advance of the charge was impeded. Estimations were made during short stoppages of the kiln and it was concluded that the charge could be taken at 6 per cent. throughout the enlarged zone of the kiln also.

#### The Use of Chains for Drying Slurry.

(123) During the past few years it has been customary greatly to increase the drying surface in the wet end of a rotary kiln by inserting a large number of short lengths of iron chain. Each chain receives heat from the kiln gases for about three-fourths of a revolution, and transfers it to the slurry in the remaining fourth. The chains may be suspended at one end or at both ends, and they are usually made from  $\frac{1}{2}$ -in. or  $\frac{3}{4}$ -in. round iron. It is found that chains last longer than large fixed flat or curved surfaces of cast iron or steel, and they are easy to renew. Their continual movement when at work tends to keep them free from lumps of drying slurry, and for a given temperature difference chains will

take up heat from hot gases about twice as rapidly as the same surface area of cast-iron plate.

Fig. 21 shows two or three links of the  $\frac{1}{4}$ -in. chain used in the kiln under consideration. Each link has a surface area of 0.128 square feet, and since there are two complete links in a length of  $4\frac{1}{2}$  in. the total surface per foot run is 0.68 square feet. The hot gases would not, however, impinge against all parts of the chain since there is a certain amount of shielding, hence for calculation purposes seven-eighths of the full surface area is used. This amounts to 0.595 square feet per foot run.

#### Heat Transfer to Chains by Convection.

(124) Various experiments have been made to find the rate at which heat can be transferred to round iron rods or tubes from a stream of hot air crossing them at right angles, and some of the results are applicable to chains. In this

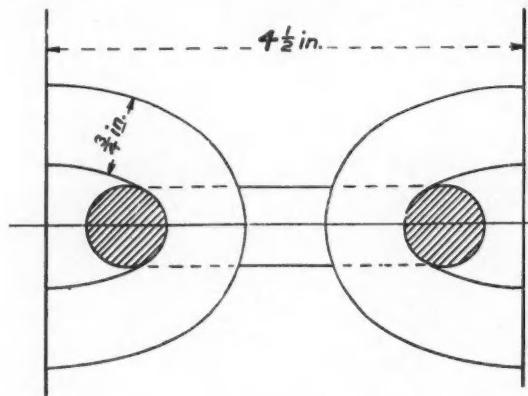


Fig. 21.

connection reference may be made to "Calculation of Heat Transmission" by Fishenden and Saunders, published by the Fuel Research Board. From a curve given on page 123, which correlates all the data available, the graph shown in Fig. 22 has been prepared. On the graph

$H_c$  = rate of heat transfer by convection in B.T.U. per square foot per hour per deg. F. temperature difference.

$V$  = gas velocity in feet per second.

The rate of heat transfer also depends to some extent on the mean temperature of the gas and the iron rod, the line  $AB$ , for instance, should be used when the mean temperature is 200 deg. F. The graph is drawn for  $\frac{1}{4}$ -in. diameter round iron rods. For  $\frac{1}{8}$ -in. diameter rods the value of  $H_c$  obtained from the graph should be multiplied by 1.08, and for  $\frac{1}{2}$ -in. rods by 0.93.

### Arrangement of Chains in the Kiln.

(125) The general arrangement of the chains in the kiln under consideration is shown by Fig. 23. The kiln where the chains occur is 8 ft. 10 $\frac{1}{2}$  in. in diameter inside the lining. Each chain is 9 ft. 6 in. long and of  $\frac{1}{2}$ -in. diameter round iron, and there are twelve points of suspension in the circle. Referring to the chain *ABC* for instance, the dimensions are arranged so that when the kiln has turned

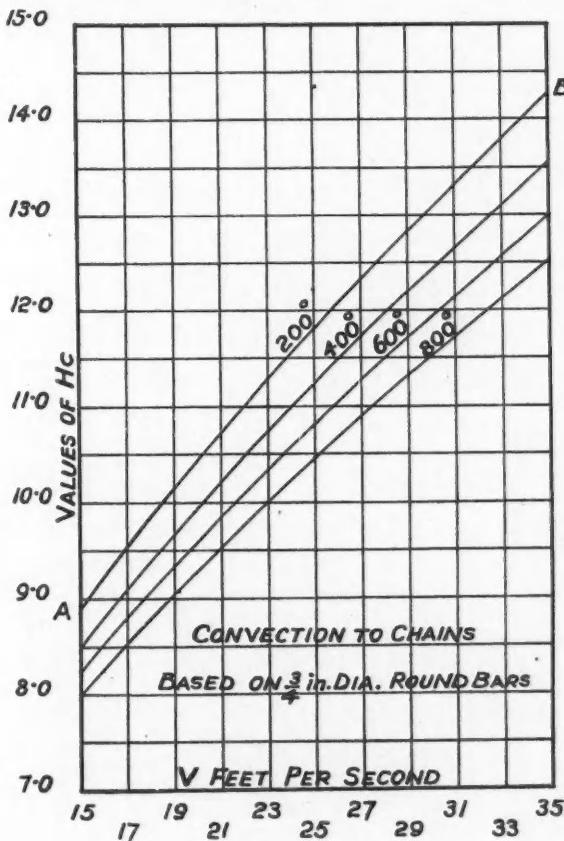


Fig. 22.

through half a revolution the chain *ABC* will lie along the arc *ADC* and only bear lightly, if at all, against the kiln lining, thus avoiding undue wear and tear.

The chains weigh 5.25 lb. per foot, and the total weight in the kiln is 14.4 tons. The charge shown in Fig. 23 is 8 per cent.

(126) To obtain further information Fig. 23 was drawn to an enlarged scale and mounted on cardboard, which was then fixed in position with the line *O 6*

vertical. On using a chain of the correct relative length and suspending it in turn in each of the twelve positions shown in the figure, it was found that on an average 71 per cent. of the chain surface is continually exposed to the hot gases and 29 per cent. is buried in the slurry.

The total length of chain used is  $648 \times 9.5$  ft., and this is spread over a kiln length of 96 ft. The available surface, see para. (123), is 0.595 square feet per foot run of chain, hence the chain surface exposed to the gases per foot run of kiln is

$$\frac{648 \times 9.5 \times 0.595 \times 0.71}{96} = 27.0 \text{ square feet.}$$

The chain surface buried in the slurry per foot run of kiln is  $\frac{29}{71} \times 27.0 = 11.0$  square feet. Since a small proportion of the chain rests on the kiln lining, clear of the slurry, the figures actually used for calculation purposes are 26.0 and 10.5.

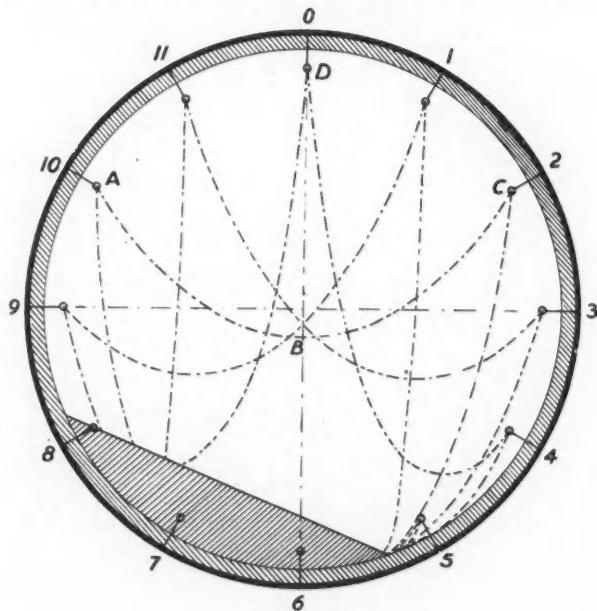


Fig. 23.

#### Gas Radiation to Chains.

(127) At the feed end of the kiln about 15 per cent. of the heat is transmitted from the gas to the chains by radiation and 85 per cent. by convection; farther along the kiln, where the chains terminate, the proportion of heat transmitted to them by gas radiation may be 30 per cent. or more. Hence it is necessary to find out how it can be calculated.

The subject of gas radiation was considered in Part II (CEMENT AND CEMENT MANUFACTURE, March 1933), where Tables Nos. II, III and IV relate to a long cylinder filled with kiln gases and give the heat radiated to a square foot of the circumference by either of the constituents  $H_2O$ , or  $CO_2$ . In this connection

$P$  = fraction by volume of either gas which is present.

$D$  = diameter of cylinder in feet.

The gas radiation was stated to depend on the product  $PD$ .

(128) The Tables also give the radiation which escapes per square foot of area from a small aperture in the flat base of a hemisphere containing gas (see Fig. 24), when  $R$ , the radius of the hemisphere, is substituted for  $D$ , the diameter of the cylinder, in the value  $PD$ . It will be noted that all the radiant beams which pass through the aperture  $O$  have the same length but are in general inclined to it at an angle such as  $\theta$ , and the area available for the escape of radiation depends upon  $\cos \theta$ .

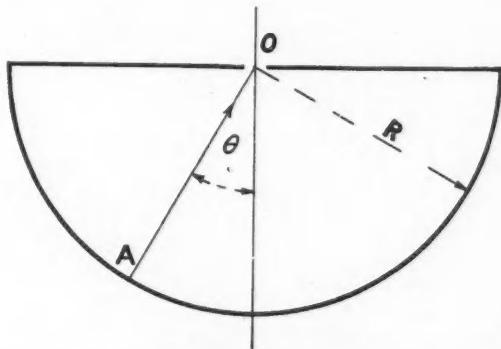


Fig. 24.

Professor Hottel uses the hemispherical shape as a standard of reference when calculating the radiation due to gas-masses of various shapes.

(129) Following on from the above the writer deduces that the radiation from a gas-filled sphere to a small spherical ball placed at the centre can be obtained, per square foot of ball area, if the radius  $R$  of the sphere is substituted for  $D$  in the value  $PD$  when the Tables are used.

(130) Returning to the chains, as shown by Fig. 23, for the purpose of calculating the gas radiation to them they are replaced by an equal surface in the shape of a large number of metallic balls of  $\frac{1}{4}$ -in. diameter or similar which are spaced all over the cross section of the kiln (see Fig. 25).

Consider for instance the ball  $A$  which is on the axis of the kiln, and suppose the surface to be divided into a number of equal areas. The quantity of heat radiated to any area will depend, from para. (128), on the average length  $R$  (as measured through the gas to the kiln lining) of the radiant beams which fall

normally upon it. This average length can be obtained by a geometrical construction, and, using  $PR$  instead of  $PD$  in the Tables, the gas radiation per square foot of area which falls upon each portion of the ball  $A$  can be obtained. An average value is then taken. It is found for the central ball at  $A$  that the same result will be obtained by taking  $0.66 PD$  instead of  $PD$  when using the Tables,  $D$  being the kiln diameter in feet inside the lining.

For a ball  $B$  placed at two-thirds of the radius, the value to use is  $0.57 PD$ , and for a ball at four-fifths of the radius the value is  $0.45 PD$ . It finally appears that an average value for a series of balls spread uniformly over the cross section is about  $0.55 PD$ . This value is used for the chains. The full surface area of twenty-six square feet per foot run of kiln, see para. (126), is used in this connection.

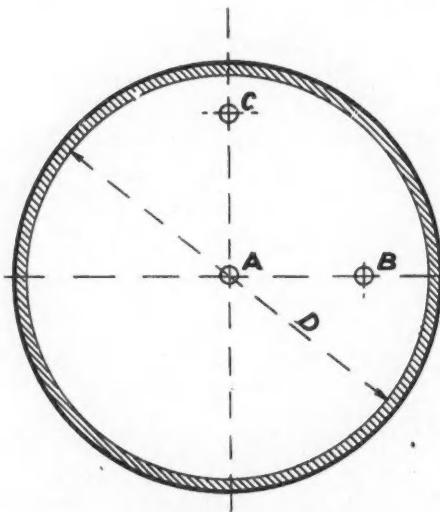


Fig. 25.

(131) With an arrangement of chains like that shown on Fig. 23 the obstruction offered to the passage of the hot gases tends to increase the heat transmitted by convection, since the gases can pass around the chains and the velocity is somewhat increased. The radiation from the gases to the kiln lining and to the chains, however, acts in straight lines and an allowance has to be made for the obstruction caused by the chains. A similar reduction is made when gas radiation acts between the particles of incandescent coke in the combustion zone of the kiln.

The advantages and the limitations of chains will be investigated in a future article in this Journal.

## The Hardening and Corrosion of Cement—VII.

By Dr. KARL E. DORSCH.

(OF THE TECHNICAL HIGH SCHOOL, KARLSRUHE, BADEN.)

### Effect of the Grain Composition of Mortar in Corrosion.

THE investigation into the corrosive action of various salt solutions upon cement has been extended to include the effect of the grain composition of the mortar. The cements used were those whose analyses are given in Table VI of the preceding article, viz.: ordinary and high-strength Portland cement, iron-ore cement, blast-furnace cement, Jura Portland cement, and aluminous cement. Standard tensile test-pieces of 1:3 mortars of these cements were made, using standard sand and Rhine sand. The latter is well graded river sand containing 10 per cent. of 0 to 0.3 mm. grains, 20 per cent. 0.3 to 0.8 mm. grains, and 70 per cent. 0.8 to 3.0 mm. grains. The percentage of mixing water (based on the cement), the temperatures of the mixing water and storage chamber, and the humidity during gauging are given in Table X.

TABLE X.

Test-piece.	Mixing water, Per cent.	Temperatur of mixing water (deg. C.).	Temperatur of storage room (deg. C.).	Humidity, Per cent.
Ordinary Portland cement, standard sand ..	9.44	18	18.3	58
" " Rhine sand ..	9.4	18.1	18.9	61
High-strength " standard sand ..	9.2	18	18.5	57
" " Rhine sand ..	9.2	18	19	61
Iron-ore cement, standard sand ..	9.3	18	18.5	60
" Rhine sand ..	9.3	18	18.5	58
Blast-furnace cement, standard sand ..	8.5	18.3	18.7	49
" Rhine sand ..	8.5	18.1	18.8	58
Jura cement, standard sand ..	9.3	18	18.5	50
" Rhine sand ..	9.3	18	18.5	50
Aluminous cement, standard sand ..	8.25	18.1	18.9	50
" Rhine sand ..	8.25	18.1	18.9	50

Ten tensile test-pieces of each kind were stored one day in air and six days in water and then transferred to the following solutions: 15 per cent. ammonium sulphate, sodium sulphate, magnesium chloride and sugar, and saturated calcium sulphate, as well as 10 per cent. magnesium sulphate, aluminium sulphate, barium chloride, sodium hydroxide and ammonium hydroxide. Comparison test-pieces were stored in distilled water. The storage room was maintained at a practically constant temperature of 18 deg. C., and the test-pieces were observed daily. The results obtained with ammonium and sodium sulphate solutions were identical with those obtained in earlier tests,<sup>28</sup> thus proving the reproducibility of the experiments.

<sup>28</sup> Probst and Dorsch, *Zement*, Nos. 10, 11, 1929.

**15 per cent. Ammonium Sulphate.**

In the case of all the cements the results fully agreed with those of the earlier experiments. Table XI shows the cements in order of increasing resistance to ammonium sulphate solution.

TABLE XI.  
AMMONIUM SULPHATE.

	Number of days before decomposition begins.					
	High-strength Portland cement.	Ordinary Portland cement.	Iron-ore cement.	Blast- furnace cement.	Jura Portland cement.	Aluminous cement.
Standard sand ...	3	10	12	25	41	Unattacked after 700 days.
Rhine sand .....	6	30	25	41	45	

The great resistance to sulphates of aluminous cement mortar is noteworthy ; there was no visible sign of decomposition after storage in ammonium sulphate for 700 days, except that a few sand grains had become detached from the edges. The tensile strength tests show, however, that this sulphate has a definite action on aluminous cement (see Table XIV). There is a considerable increase of strength at 200 days as compared with test-pieces stored in distilled water : thus for the standard-sand mortar the values are 498 lb. per sq. in. in distilled water and 762 lb. in ammonium sulphate ; for Rhine-sand mortar the corresponding figures are 690 lb. and 1,133 lb. Only after 500 days does the strength of the standard-sand test-pieces fall to 321 lb. per sq. in., and even then there is no sign of expansion cracks. In contrast to this all the other cement mortars, both of standard and Rhine sand, have no determinable tensile strength after 200 days in ammonium sulphate solution.

**15 per cent. Sodium Sulphate.**

The experiments in sodium sulphate solution also agreed with the results of earlier work of the author. With the exception of the ordinary and high-strength Portland cement test-pieces, which were completely decomposed to a muddy mass in 200 days, all the cements showed only slight traces of attack after 500 days. The blast-furnace and iron-ore cement mortars showed fine expansion cracks at the edges after 500 days. On repeating the tests the blast-furnace cement proved more resistant to sodium sulphate solution, although this was only evident in the tensile tests after 200 days. This interesting result is to be explained by the oxidation of the calcium sulphide of the blast-furnace cement to calcium sulphate on storage ; the presence of calcium sulphate favourably affects the resistance of the cement. The Jura Portland cement was unattacked after 500 days. With the standard-sand aluminous-cement test-pieces grains of sand became detached from the edges after 500 days, but there was no sign of cracks.

TABLE XIV.  
TENSILE STRENGTHS IN LB. PER SQ. IN.

	Days	DISTILLED WATER	$(NH_4)_2SO_4$	$Na_2SO_4$	$CaSO_4$	$MgSO_4$	$MgCl_2$	SUGAR	$BaCl_2$	$Al_2(SO_4)_3$	$NH_4OH$	$NaOH$
<i>High-strength P. C. &amp; Standard Sand</i>	200	469	0	0	434	—	—	—	—	—	—	—
	500	547	0	0	0	190	297	474	566	0	447	522
	700	586	0	0	0	0	321	402	—	0	505	624
	900	—	0	0	0	0	301	384	—	0	—	—
<i>do.. &amp; Rhine Sand</i>	200	666	0	569	664	—	—	—	—	—	—	—
	500	668	0	0	505	190	546	631	724	228	609	809
	700	754	0	0	414	0	666	421	—	0	711	702
	900	—	0	0	—	0	491	373	—	0	—	—
<i>Ordinary P.C. &amp; Standard Sand</i>	200	419	0	0	235	—	—	—	—	—	—	—
	500	472	0	0	237	0	317	383	411	193	610	381
	700	532	0	0	256	0	324	489	—	0	496	516
	900	—	0	0	309	0	378	321	—	0	—	—
<i>do.. &amp; Rhine Sand</i>	200	547	0	361	476	—	—	—	—	—	—	—
	500	646	0	0	596	0	614	464	710	461	731	583
	700	772	0	0	788	0	555	333	—	459	755	782
	900	—	0	0	794	0	510	256	—	—	—	—
<i>Iron-ore Cement &amp; Standard Sand</i>	550	586	0	256	567	280	360	—	—	—	—	—
<i>Blastfurnace CEMENT &amp; Standard Sand</i>	200	532	0	580	445	—	—	—	—	—	—	—
	500	680	0	460	491	270	357	431	499	613	684	584
	700	664	0	—	722	259	361	506	—	628	700	630
	900	—	0	—	654	—	443	505	—	—	—	—
<i>do.. &amp; Rhine Sand</i>	200	727	0	832	610	—	—	—	—	—	—	—
	500	812	0	—	724	799	690	469	731	956	633	822
	700	785	0	—	931	826	729	677	—	910	714	1014
	900	—	0	—	1010	—	729	860	—	—	—	—
<i>Jura P.C. &amp; Standard Sand</i>	200	540	0	445	536	—	—	—	—	—	—	—
	500	685	0	303	671	452	394	477	434	782	779	791
	700	697	0	—	784	525	614	328	—	717	617	668
	900	—	0	—	852	—	596	269	—	—	—	—
<i>do.. &amp; Rhine Sand</i>	200	654	0	987	704	—	—	—	—	—	—	—
	500	708	0	—	843	704	718	476	546	752	686	813
	700	801	0	—	856	795	832	564	—	688	806	802
	900	—	0	—	944	—	708	668	—	—	—	—
<i>Aluminous CEMENT &amp; Standard Sand</i>	200	498	762	666	600	—	—	—	—	—	—	—
	500	523	321	547	611	801	580	610	644	537	631	336
	700	609	—	—	658	685	776	712	—	539	496	236
	900	—	—	—	718	—	684	592	—	—	—	—
<i>do.. &amp; Rhine Sand</i>	200	690	1133	880	570	—	—	—	—	—	—	—
	500	822	—	—	745	970	840	897	711	812	927	660
	700	838	—	—	791	961	873	911	—	842	849	567
	900	—	—	—	889	—	940	957	—	—	—	—

The tensile tests showed that on storage in sodium sulphate solution the strength of the test-pieces at first increases. At 200 days blast-furnace cement with standard sand gave 580 lb. per sq. in. (against 512 lb. in water) and with Rhine sand 832 lb. (against 727 lb.): Jura Portland cement with Rhine sand gave 987 lb. (against 654 lb.): aluminous cement with standard sand gave 666 lb. (against 498 lb.) and with Rhine sand 880 lb. (against 690 lb.) The Portland cements gave low values at 200 days and were already partly decomposed.

#### 10 per cent. Magnesium Sulphate.

HIGH-STRENGTH PORTLAND.—With standard sand the first fine cracks appear at the edges after 80 days. In eight months the edges are entirely covered with larger cracks, and the test-pieces are wholly coated with a gelatinous layer

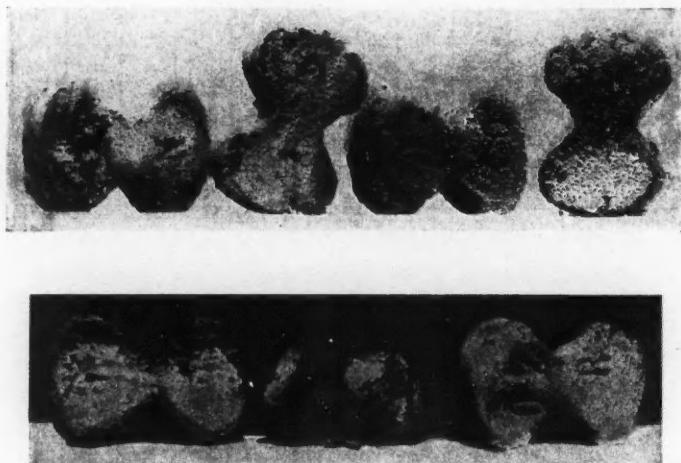


Fig. 60.—Test-pieces (standard sand above, Rhine sand below) after 700 days in 10 per cent. magnesium sulphate; left to right—high-strength Portland, ordinary Portland, blast-furnace and iron-ore cement.

of  $Mg(OH)_2$  which is more or less pronounced according to the quantity of  $Ca(OH)_2$  formed during setting and hardening.



This  $Mg(OH)_2$  formation is most abundant in the case of the Portland and iron-ore cements, which form more  $Ca(OH)_2$  on hydration than cements of lower lime content.

With high-strength Portland cement and Rhine sand decomposition begins after 92 days and proceeds much more slowly than with the standard-sand test-pieces. Fig. 60 shows the appearance after 700 days. The test-pieces

had no strength at 700 days. At 500 days the tensile strength was 190 lb. per sq. in. for both standard and Rhine sand (see Table XIV).

**ORDINARY PORTLAND CEMENT.**—The attack commenced later than with high-strength Portland cement, viz.: after 123 days with standard sand and 268 days with Rhine sand. After 700 days the test-pieces were less decomposed than for the high-strength cement (see Fig. 60). Rhine-sand and standard-sand test-pieces were equally attacked in this case, although Fig. 60 appears to show greater resistance on the part of the standard sand. At 500 days the tensile strength of standard-sand test-pieces was zero with both sands.

**IRON ORE CEMENT.**—As would be expected from the results of the experiments on cement cubes described earlier, the mortar test-pieces show the relatively low resistance of iron-ore cement to magnesium salts. With standard sand the first expansion cracks appear in 83 days; these rapidly widen, until in 550 days the test-pieces already have the appearance shown in Fig. 60. The tensile strength of standard-sand test-pieces at 550 days is 280 lb. per sq. in.

**BLAST-FURNACE CEMENT.**—With standard sand the first cracks appear in 313 days. After 650 days the whole of the edges of the test-pieces break away (see Fig. 60). The Rhine-sand test-pieces on the other hand are undamaged. With standard sand the tensile strength at 500 days has fallen to 270 lb. per sq. in. and to 259 lb. at 700 days, compared with 522 lb. in water. With Rhine sand the tensile strength remains practically equal to the strength on water storage.

The Jura Portland and aluminous cements appear to be unattacked even after 700 days in magnesium sulphate, and their strength is not reduced except in the case of Jura Portland cement and standard sand (see Table XIV).

Table XII summarises the times before decomposition begins in the case of standard test-pieces of the various cement mortars stored in 10 per cent.  $MgSO_4$  solution.

TABLE XII.  
MAGNESIUM SULPHATE.

	Number of days before decomposition begins.					
	High-strength Portland cement.	Ordinary Portland cement.	Iron-ore cement.	Blast- furnace cement.	Jura Portland cement.	Aluminous cement.
Standard sand ...	80	123	83	313	Unattacked after 700 days.	
Rhine sand .....	92	268	—		Unattacked after 700 days.	

#### Saturated Calcium Sulphate.

Probst and Dorsch have already shown (see ref. 28) the effect of the granular composition of the cement on the resistance of mortar and concrete to chemical

attack. This effect becomes more evident as the velocity of attack is retarded, i.e., the closer the rate of decomposition corresponds to the conditions met with in practice. This can clearly be seen with the less aggressive salt solutions, and particularly with calcium sulphate solution. Fig. 61 obviously shows that the Rhine-sand test-pieces of high-strength Portland cement (left) and ordinary Portland cement (right) are much less attacked than the standard-sand test-pieces. This difference is to be attributed to the greater density of the Rhine-sand mortars. It is a purely mechanical, not a chemical effect. If two test-pieces of different porosity are immersed in water, that with the greater porosity will more rapidly absorb water and become saturated. Thus in the case of a standard-sand test-piece—which contains many more macropores than a Rhine-

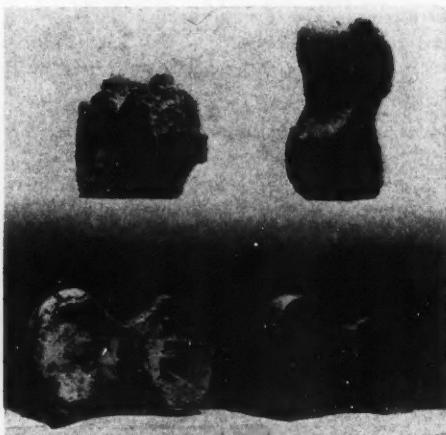


Fig. 61.—Test-pieces (standard sand above, Rhine sand below, after 900 days in saturated calcium sulphate: high-strength Portland left, ordinary Portland right).

sand test-piece—the attacking solution can penetrate to a greater depth, and the attack proceeds not only from the outer surface but also from the inner depths of the body. With Rhine sand, on the other hand, the attack takes place chiefly from the surface.

A microscopic examination of surfaces exposed by the tensile test in the case of high-strength Portland cement mortars, after careful polishing, shows an entirely different appearance between the standard-sand and Rhine-sand test-pieces (Figs. 62 and 63). Fig. 62 clearly shows the porosity of the standard-sand structure, and the manner in which the attacking solution (the clear portions of the photomicrograph) has penetrated into the material. Further, the character of the boundary between test-piece and solution is plainly to be seen.

The Rhine-sand test-piece (Fig. 63) offers a decided contrast. As a result of the grading of the sand the material contains much finer pores. The fine sand and cement particles closely hem in the coarser sand grains and thus offer resistance to the penetration of the salt solution. The surface of the test-piece is covered with a thick layer of calcium carbonate which also renders the penetration of the attacking liquid extremely difficult.

Chemical analyses confirmed these statements. Rhine-sand and standard-sand tensile test-pieces which had been stored in calcium sulphate solution were removed and thoroughly washed with distilled water to eliminate all traces of solution on the surface. The test-pieces were then pulled and the halves carefully separated into layers by a sharp chisel. The fraction formed by the layer 4 to 5 mm. deep is termed the "outer," and the mortar more than 10 mm.

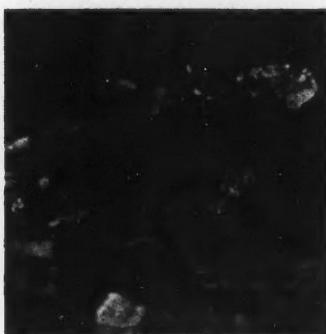


Fig. 62.—Standard-sand test-pieces.

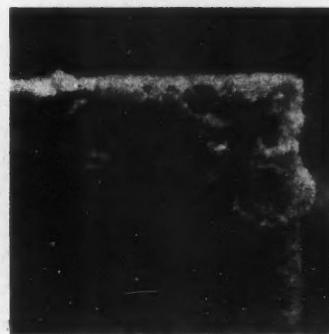


Fig. 63.—Rhine-sand test-pieces.

deep is called the "inner" fraction. These two fractions were dried at 100 deg. C., ground in a mortar, again dried, and the SO<sub>3</sub> contents then determined. The following results were obtained for high-strength Portland cement mortars of standard sand and Rhine sand respectively: Standard sand, "outer" fraction 9.91 per cent. SO<sub>3</sub> (calculated on the cement), "inner" fraction 3.72 per cent.; Rhine sand, "outer" fraction 2.94 per cent., "inner" fraction 1.81 per cent. Thus the standard-sand test-piece clearly contains much more SO<sub>3</sub> than the Rhine-sand test-piece. The Rhine-sand test-piece is unattacked by the solution at a depth of 10 mm.; the SO<sub>3</sub> content of the "inner" fraction is practically the same as that of the cement (1.75 per cent.) before gauging. By contrast the SO<sub>3</sub> content of the "outer" fraction of the standard-sand test-piece is almost six times that before immersion in the solution. These experiments clearly show the increased resistance of mortar or concrete to aggressive solutions as a result of using a carefully graded sand.

The decomposition of the different cements in calcium sulphate solution takes place as follows.

The first sign of attack in the case of high-strength Portland cement is the occurrence of expansion cracks, which appear after 305 days in the standard-sand test-piece and after 328 days with Rhine sand. After 900 days the standard-sand mortar is completely broken up, but with Rhine sand the attack has only resulted in cracks at the edges (see Fig. 61). The standard-sand tensile strength is 434 lb. per sq. in. at 200 days and zero at 500 days. The Rhine-sand tensile strength falls off much more slowly; at 200 days it is 66.4 lb., at 500 days 50.5 lb., at 700 days 41.4 lb., and zero only at the end of 900 days (see Table XV).

With ordinary Portland cement and standard sand no sign of attack is visible after 500 days, but cracks begin to form after 530 days and in 700 days the attack has made considerable progress (Fig. 61). The Rhine-sand test-piece, by contrast, is unattacked after 900 days. The tensile tests confirm these observations. With Rhine sand there is no reduction in strength at 900 days, while the standard-sand strength is considerably reduced (to 30.9 lb. per sq. in.).

With the other cements there is no deterioration evident after 90 days. On the other hand the strength of the blast-furnace, Jura Portland, and aluminous cements is generally considerably increased (see Table XIV). Table XIII summarises the lapses of time before the beginning of decomposition in the case of the different cements.

TABLE XIII.  
CALCIUM SULPHATE SOLUTION.

	High-strength Portland cement.	Number of days before decomposition begins.				
		Ordinary Portland cement.	Iron-ore cement.	Blast- furnace cement.	Jura Portland cement.	Aluminous cement.
Standard sand ..	305	530		Unattacked after 900 days.		
Rhine sand .....	328		Unattacked after 900 days.			

#### Aluminium Sulphate Solution.

In aluminium sulphate solution the behaviour of the cements is very similar to that in saturated  $\text{CaSO}_4$ . Aluminium sulphate was investigated because it was expected that calcium sulphoaluminate—only seldom found in the other sulphate solutions—would be more prolifically produced. This, however, was not found to be the case, presumably because the concentration of the solution was too high. The reaction proceeded with the formation of calcium sulphate and aluminium hydrate, the latter separating on the surface of the test-piece and forming a protective layer. This results in the rate of decomposition of the cements being practically the same as in  $\text{CaSO}_4$  solution. Except for the high-strength and ordinary Portland cements, the cements are not attacked and there is no reduction in strength. With both high-strength and ordinary Portland cements and standard sand the strength is zero after 900 days (Table XIV). With both these cements decomposition begins at 60 days and after 90 days the surfaces of the test-pieces are severely attacked.

### Solutions of the Alkaline Earth Chlorides.

Of these,  $MgCl_2$  is the most interesting since it occurs in considerable quantities in almost all natural waters. Its attack on cement proceeds according to the equation.



The  $CaCl_2$  formed passes into solution and the insoluble  $Mg(OH)_2$  is deposited on the test-pieces and the bottom of the container as a dense white precipitate which exerts a strong protective influence against further attack.

The test again comprised standard-sand and Rhine-sand mortars of the various cements stored in 15 per cent.  $MgCl_2$  solution. They showed that, apart from the precipitation of  $Mg(OH)_2$ , there was no visible sign of attack after 900 days. The tensile tests showed that actually there was some attack. It will be seen from Table XIV that the strengths of both standard-sand and Rhine-sand mortars of high-strength and ordinary Portland cements, as well as the standard-sand mortars of iron-ore and blast-furnace cement, are considerably reduced. A recent paper by S. Michelsen<sup>29</sup> shows that  $MgCl_2$  solution can seriously attack Portland cement. This form of attack must receive careful attention in connection with the frequent present-day practice of laying magnesium oxychloride floors on Portland cement concrete.

$CaCl_2$  and  $BaCl_2$  solutions have no effect on cement, as was shown by the experiments with 10 per cent.  $BaCl_2$  solution. There was no indication of change after 700 days, and in the majority of cases the strengths at 500 days remained the same as with distilled water storage (Table XIV).

### 15 per cent. Sugar Solution.

It is well known that sugar solutions attack cement, calcium saccharate being formed and dissolved out. The present tests showed that the attack is extremely slow owing to the formation of a protective layer of  $CaCO_3$  on the test-pieces by the  $CO_2$  dissolved in the water. The sugar solution must be renewed annually since it ferments and the concentration is thereby changed.

All the cements showed signs of attack after 900 days. With ordinary high-strength, and Jura Portland cements and standard sand, sand grains had broken away from the edges owing to softening of the structure. The Rhine-sand test-pieces of ordinary Portland cement were unexpectedly seriously attacked; they were dissolved to a depth of 5 to 10 mm. and the sand was deposited on the bottom of the container; no expansion cracks were found with this type of decomposition. All the previous experiments had clearly proved the superior resistance of Rhine-sand mortars as compared with standard sand, and an explanation of this surprising behaviour must be sought. It was finally concluded that acetic acid bacilli had accidentally gained access to the solution (possibly from the wood of the container) and had effected an oxidation of the alcohol to acetic acid. The acid—the presence of which was proved chemically—had

<sup>29</sup> S. Michelsen, *Tonind. Zeit.*, No. 76, p. 1068, 1931.

caused the decomposition of the Rhine-sand test-pieces. It reacts with the lime of the cement, forming calcium acetate. The solution of the cement and the lack of the usual expansion cracks was thus explained. It was of no avail to renew the sugar solution, since the acetic bacilli had penetrated into the test-pieces and could not be removed even by thorough washing with distilled water.

The tensile tests (Table XIV) showed considerable fall in the strength of the Rhine-sand and standard-sand tests-pieces of high-strength, ordinary, and Jura Portland cements.

#### 10 per cent. Alkali Hydroxide Solutions.

Alkali hydroxides react with the calcium aluminates of cements to form alkali aluminates, and the reaction is naturally less extensive when the alumina content of the cement is low. It was previously accepted that cements, which are strongly basic, resisted the attack of other basic substances. This theory was, however, disproved by the work of the California Highway Research Laboratory,<sup>20</sup> which showed that Portland cement concrete is seriously attacked by sodium and potassium hydroxide solutions. This was explained by stating that the  $\text{Ca}(\text{OH})_2$  formed on hydration has a greater solution pressure in basic media (i.e., in NaOH and KOH solutions) than in water, and that calcium hydro-silicates have an appreciable solution pressure in basic media. This explanation is improbable, however, since decomposition as pronounced as that observed could hardly be explained by increased solution pressure. The hypothesis that the calcium aluminates are attacked is far more probable and is easy to test. It is only necessary to compare the results obtained with cements of widely different alumina content such as Portland and aluminous cements. In the experiments the six types of cement were again used, and test-pieces were stored in 10 per cent. solutions of sodium hydroxide and ammonia solutions.

The Rhine-sand and standard-sand test-pieces of ordinary, high-strength, Jura Portland and blast-furnace cements showed no visible sign of attack after storage in NaOH for 700 days. This is confirmed by the tensile test results, which are equal to those of the comparison specimens stored in distilled water. In the case of aluminous-cement mortars there is again no visible sign of attack, but the strengths have fallen off seriously. The standard-sand test-pieces at 500 days gave 336 lb. per sq. in. against 523 lb. in water, and at 700 days 236 lb. against 609 lb. The Rhine-sand test-pieces at 500 days gave 660 lb. against 822 lb. in water, and at 700 days 567 lb. against 838 lb. The interior of the aluminous cement was attacked by the sodium hydroxide, but with Portland and the other cements no attack could be detected after two years. The theory that the attack of cement by alkalis is due to attack on the calcium aluminates thus finds experimental support. It is probable that in the further progress of the reaction zeoliths (i.e., water-containing alkali—or alkaline earth-alumino-silicates) are formed with increase of volume, leading ultimately to the bursting apart of the test-pieces.

<sup>20</sup> *Concrete*, 1929.

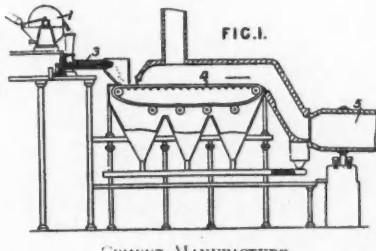
With ammonia water there was no sign of attack with any cement, including aluminous. The strengths also did not deteriorate (see Table XIV). According to the United States theory decomposition was also to be anticipated in this solution, since the solution pressure of the  $\text{Ca}(\text{OH})_2$  should be greater than in pure water. Since there was no such decomposition the solution pressure theory must be held to be invalid.

*(To be continued.)*

## Recent Patents Relating to Cement.

### Cement Manufacture

389,083.—Triggs, W. W., 57, Lincoln's Inn Fields, London (Polysius Akt.-Ges., G., Dessau, Germany). Aug. 7, 1931.



CEMENT MANUFACTURE

In the manufacture of cement by the wet method, the raw slurry is first partly dehydrated in a filter (1) and then fed to an extrusion press (3) fitted with a device for cutting the extruded material into small pieces, these pieces being delivered to a gas-pervious conveyor (4) on which they are partially burnt by the passage therethrough of hot gases from the rotary kiln (5) in which the burning is completed. To pre-

vent caking, the cut pieces are sprinkled with or rolled in dry raw meal prior to or during their delivery to the conveyor (4), the raw meal being preferably of the same chemical composition or made from the same rock as the slurry. A modification is described in which the endless conveyor (4) is replaced by a rotary frustro-conical stepped grate; a hopper-shaped grate may also be employed.

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## Artificial Pozzolanas.

THE investigations on pozzolanas being carried out by the Building Research Station in co-operation with certain industrial firms, are now in their fifth year, and the latest report of the Station deals with certain phases of these investigations.

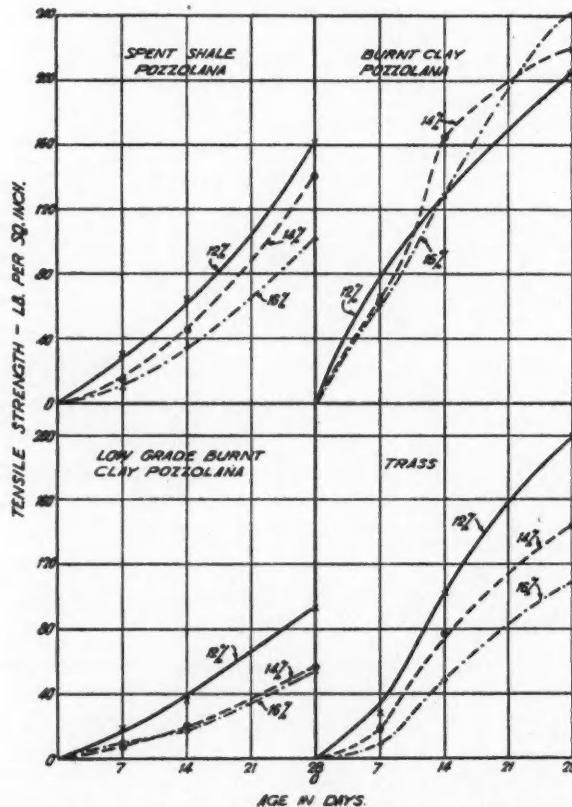


Fig. 1.—Tensile strengths of 2 : 1 : 9 (by weight). Pozzolana: hydrated zinc : standard sand mortars with water contents of 12, 14 and 16 per cent., after storage in water.

**Pozzolana Mortars.**—A study is now in progress on the strength of plastic mortars, and Fig. 1 shows results for a spent shale, two burnt clays, and a Rhenish trass pozzolana, all ground to leave a small residue on a sieve having 180 meshes

to the inch, and tested in hydrated lime-pozzolana mortars. The strengths are lower than those of the dry mortars previously reported.

Some similar tests have been carried out on plastic cement-pozzolana mortars. The substitution of pozzolana for 20 per cent. of the cement in dry mortar mixes has previously been found to lead to somewhat increased strengths from 28 days and upwards; that of 40 per cent. to reduced strengths at 7 days, little changed strengths at 28 days, and increased strengths at later ages; and that of 60 per cent. to reduced strength at 7 days and little changed strengths at 28 days and 3 months when compared with mortars with cement alone. With plastic mortars it is found that the replacement of cement by pozzolana leads to reduced strengths up to 3 months, but that at six months the substitution of up to 40 per cent. pozzolana is not prejudicial to the strength. These results on plastic mortars bear a much closer resemblance to the data obtained on pozzolana concrete mixes than do the dry mortar data.

Work is also in progress on the absorption of water by bricks from mortars and the influence of this action on the properties of the mortar. The strength of mortars cast on various porous backgrounds, made to simulate bricks of differing degrees of suction, and the volume changes occurring in such mortars during and subsequent to hardening, are being investigated. The replacement of cement by pozzolana increases the power of the mortar to retain its water against the suction of brickwork and also increases the workability of the mortar as determined by the flow table method. This effect may be found to have an important bearing on the design of cement mortars for renderings.

**Effect of Pozzolana on Resistance of Concretes to Sea Water and Salt Solutions.**—Piles and cylinders containing a spent shale pozzolana have shown a satisfactory behaviour in sea water up to two years and a more comprehensive series of piles and cylinders with spent shale and burnt clay pozzolanas is now being laid down. A series of measurements has also been made on the expansion of cement-pozzolana mortars immersed in solutions of sodium and magnesium sulphates. Briefly, 5 in. by 1 in. cylindrical rods made from mortars of 1 : 1 : 6 cement : pozzolana : standard sand were cured in water for one week and then immersed in 5 per cent. solutions of (a) sodium sulphate, and (b) magnesium sulphate and their expansions measured periodically. Cement replaced the pozzolanas in one series, the resulting mix thus consisting of 1 : 3 cement : sand. The expansions given in Table I represent the difference between the expansion shown by corresponding rods in water storage and in the salt solutions and are the mean of four specimens in each case.

The 1 : 3 cement : sand mortars showed an expansion of 0.1 per cent. within fifteen weeks, while the pozzolana mortars withstood the action of 5 per cent. magnesium sulphate for over 100 weeks before showing serious expansion. In 5 per cent. sodium sulphate solution no sign of deterioration of the pozzolana mortars has been found in 140 weeks. There is little difference in the behaviour

of the artificial and the natural pozzolanas and all commenced to deteriorate seriously in 5 per cent. magnesium sulphate solution from 100 weeks upwards.

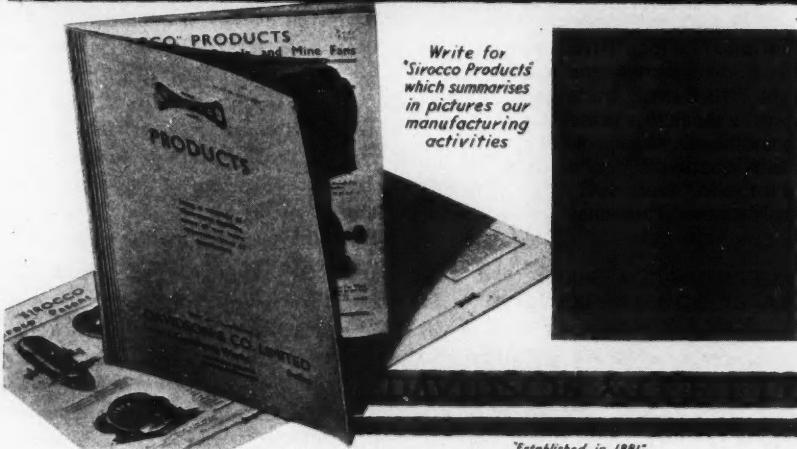
TABLE I.  
EXPANSION OF PORTLAND CEMENT : POZZOLANA : SAND MORTARS IN SULPHATE SOLUTIONS.

Age (weeks)	Cement.		Per cent. linear expansion.				Trass.		Santorin Earth.	
			Burnt clay.	Spent shale.	(a)	(b)				
	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)	(a)	(b)
12	0.070	0.054	0.000	0.004	0.006	0.008	0.014	0.016	0.010	0.010
24	0.146	0.252	0.004	0.002	0.006	0.012	0.014	0.024	0.012	0.016
40	0.240	0.710	-0.004	0.004	0.006	0.022	0.012	0.022	0.004	0.014
60	—	—	-0.014	0.006	-0.006	0.014	-0.006	0.006	-0.010	0.010
80	—	—	-0.024	-0.004	-0.012	0.020	-0.010	0.010	-0.020	0.004
100	—	—	-0.024	0.030	-0.018	0.038	-0.016	0.032	-0.028	0.004
120	—	—	—	0.082*	-0.026	0.072	-0.022	0.094*	-0.032	0.000*

\* These rods had expanded laterally and showed longitudinal cracks at this age. (a) = 5 per cent. sodium sulphate solution. (b) = 5 per cent. magnesium sulphate solution.

It may be concluded that the behaviour of concrete containing artificial pozzolanas in salt waters will not be less favourable than that of concretes containing natural pozzolanas for which practical experience over a long period is available.

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électrostatique à tambour	drum type separator	Trommelabscheider	separador de tipo de tambor
électrostatique centrifuge	centrifugal separator	Zentrifugalabscheider	separador centrifugo
électrostatique par l'air	air separation	Windsichtung	separación por aire
silice	silica	Kieseläsäure	silice
siliceux	siliceous	kieseläsärhaltig	siliceo
silo	bin	Behälter	silo
sodium	sodium	Natrium	sodio
solubilité	solubility	Löslichkeit	solubilidad
solution, liqueur	solution	Lösung	solución
solvant	solvent	Lösungsmittel	disolvente
soudre, suer	to weld	schweissen	soldar
soufre	sulphur	Schwefel	azufre
soupape, valvule	valve	Ventil	válvula
soute	bunker	Bunker	carbonera
spatule	spatula	Spatel	espátula
station d'énergie,	generating station	Kraftstation	central de energía
station génératrice ;			
station d'énergie	power station	Kraftstation	centrale de energía ;
substance	compound	Bestandteil	centrale eléctrica
suer, soudre	weld, to	schweissen	compuesto
support	support	Lager (Kugel- etc.)	soldar
surchauffer	superheat, to	überhitzen	apoyo
surchauffeur	superheater	Ueberhitzer	recalentar
surcharge	overload	Überlastung	recalentador
surface	surface	Oberfläche	sobrecarga
sursaturé	supersaturated	übersättigt	superficie

**T**

table d'alimentation	apron feeder	Telleraufgabe	mesa de alimentación
tableau de distribution	switchboard	Schaltafel	cuadro de distribución
tambour	shell	Mantel (Ofen)	cubierta o envolvente
tamis	{ screen sieve	Sieb	tamiz
tamis cylindrique	revolving screen	Trommelsieb	criba giratoria
tasser per secousses	shaking (to compact)	einrätteln	asentar por sacudidas
temps de prise	setting-time	Abbindezeit	tiempo de fraguado
tension	voltage	Spannung (elektr.)	voltaje
tension de la vapeur	vapour pressure	Dampftension	tensión del vapor
tension superficielle	surface tension	Oberflächenspannung	tensión superficial
thermo-couple	thermo-couple	Thermoelement	termo-par
tirage mécanique	induced draught	Saugzug	tiro forzado
tiroir	slide valve	Schiebeventil	valvula corredera
tissu filtrant	filter cloth	Filtertuch	pañó filtrante
titrer	titrare, to	titrieren	valorar
tôle	sheet iron	Eisenblech	plancha de hierro
tonne	ton	Tonne	tonelada
tour	lathe	Drehbank	torno
tourillon	trunnion	Zapfen (Welle)	muñón
tourillon, goujon	gudgeon	Zapfen, Bolzen	chaveta

T			
transmission de la chaleur	heat transmission	Wärmeübertragung	transmisión del calor
transporteur à augets	tray conveyor	Kastentransporteur	transportador de artesas
transporteur à courroie	belt conveyor	Bandtransporteur	transportador de correa
transporteur aérien	cableway	Seilbahn	transportador aéreo de cable
transporteur à secousses	shaker conveyor	Schütteltransporteur	transportador de sacudidas
transporteur à va-et-vient	shuttle conveyor	Schütteltransporteur	transportador de sacudidas
travail d'une équipe, poste	shift	Arbeitschicht	turno
trémie	hopper	Trichterbehälter	tolva
trempe	tempering	Tempern	tempile
trépied	tripod	Dreifuss	tripode
trépied en fer, triangle	wire triangle	Drahtdreieck	triángulo de alambre
treuil	winch	Winde	torno, cabrestante
tube	tube	Rohr	tubo
tube broyeur	tube mill	Rohrmühle	refino tubular
tube broyeur compound	compound mill	Verbundmühle	molino combinado
tube capillaire	capillary tube	Kapillarrohr	tubo capilar
turbo-alternateur	turbo-generator	Turbogenerator	turbo generador
tuyau du brûleur	burner pipe	Brenzrohr	tubería del mechero
tuyau souple	hose pipe	Gelenkrohr, -schlauch	manguera
tuyère	nozzle	Düse	boquilla
type étoile-triangle	star-delta type	Sterndreiecktyp (elektr.)	tipo de estrella triángulo
U			
usage	use	Verbrauch	aplicación
usine	{ factory	Fabrik	fábrica
	{ works	Werk, Fabrik	fábrica
usine, moulin	mill	Mühle	molino
usure	wear	Abrnutzung	desgaste
V			
valvule, soupape	valve	Ventil	válvula
vanne papillon	throttle valve	Winddrosselschieber	válvula de cuello
vapeur	steam	Dampf	vapor
ventilateur	fan	Ventilator	ventilador
vidange au moyen d'un système à chaîne	chain discharge	Kettenentleerung	descarga de cadena
vide	void	Hohlraum	hueco
vis alimentaire	feeding screw	Zuführschnecke	tornillo alimentador
vis mélangeuse	mixing screw	Mischschnecke	tornillo mezclador
viss transporteuse	screw conveyor	Schnecke, Schrauben-transporteur	transportador de tornillo
vitesse	{ speed	Geschwindigkeit	velocidad
vitesse initiale	initial speed	Anfangsgeschwindigkeit	velocidad inicial
volant	fly-wheel	Schwungrad	volante
W			
wagon à caisse basculante	tippler truck	Kippwagen	vagoneta volquete
Z			
zone de cuisson	burning zone	Sinterzone	zona de clinkerización

(To be continued.)

## Research on Cement.

THE following notes are from the Report of the Building Research Station for the year 1932, and describe some of the investigations in progress on problems relating to cement.

**Calcium Silicates.**—Certain points arising out of the lime-solution-extraction method of determining lime have necessitated some study of the hydrated calcium silicates, and in particular of the amounts of lime removed from them by extraction with lime solutions of various concentrations. While the data are as yet incomplete, there appears little doubt that in set cements there exists a hydrated calcium silicate of higher lime content than the monocalcium silicate, that it is stable only in nearly saturated lime solutions, and that it exercises a marked effect on every method so far proposed for the estimation of free lime in set cements.

**Fineness of Cements.**—Further work has been done on the analysis of the particle size of cements by sedimentation methods. The chief difficulty in such methods is to ensure complete dispersion of the cement in the oil medium. A combination of heating with vigorous stirring has been found more effective than the use of the dispersing agents which were tried. There is, however, no reliable means of ascertaining that dispersion is complete.

**Rate of Hydration of Cement.**—Study of the rate of hydration of cement,

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as measured by an arbitrarily defined "combined water" content, has rendered desirable further consideration of the manner in which water is combined in a set cement. In continuation of previous work on the relation between the rate of strength development and the rate of hydration of cement, an investigation has been carried out with ten Portland cements, including normal, rapid-hardening, white, and waterproofed cements. The effect of various water-cement-ratios on the rate of hydration of neat cements has been studied and the amounts of water have been determined which are retained by the set cements, after heating to definite temperatures, at various ages. The combined water can be arbitrarily defined in terms of the ignition loss at selected temperature of samples previously dried at 110 deg. C. A correction is applied for the loss on heating the original ungauged cement at 110 deg. C., and where necessary for absorption of carbon dioxide. When ignition losses corrected for these factors are plotted against the crushing strengths of concretes at corresponding ages up to 28 days it is found that there is a fair relation between the extent of hydration and strength developed. This promises to provide a useful method for the study of cement strengths in very small samples. The report contains a curve obtained by plotting the difference between the losses at 550 deg. C. of ungauged cements and the same cements made up into neat cement cubes with a water-cement-ratio of 0.245, against the crushing strength of 4 in. cubes of 1:2:4 concrete with a water-cement-ratio of 0.60, after storage in water for periods up to 28 days.

In the case of tensile strengths it is found that for dry mortars, normal and rapid-hardening cements fall into two groups. When wet mortars are considered, however, it appears that the same relationship holds fairly well for both.

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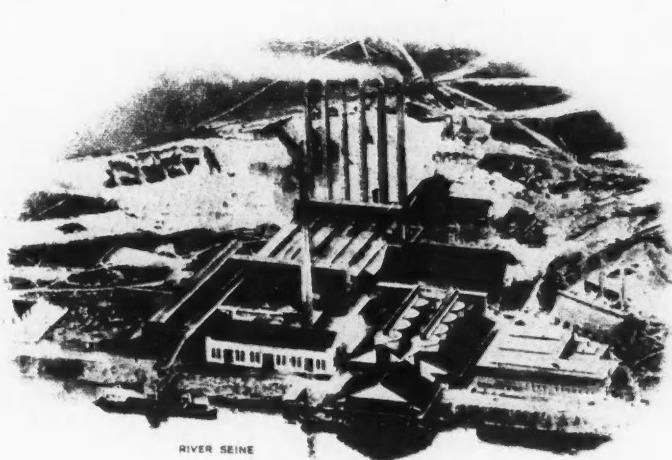
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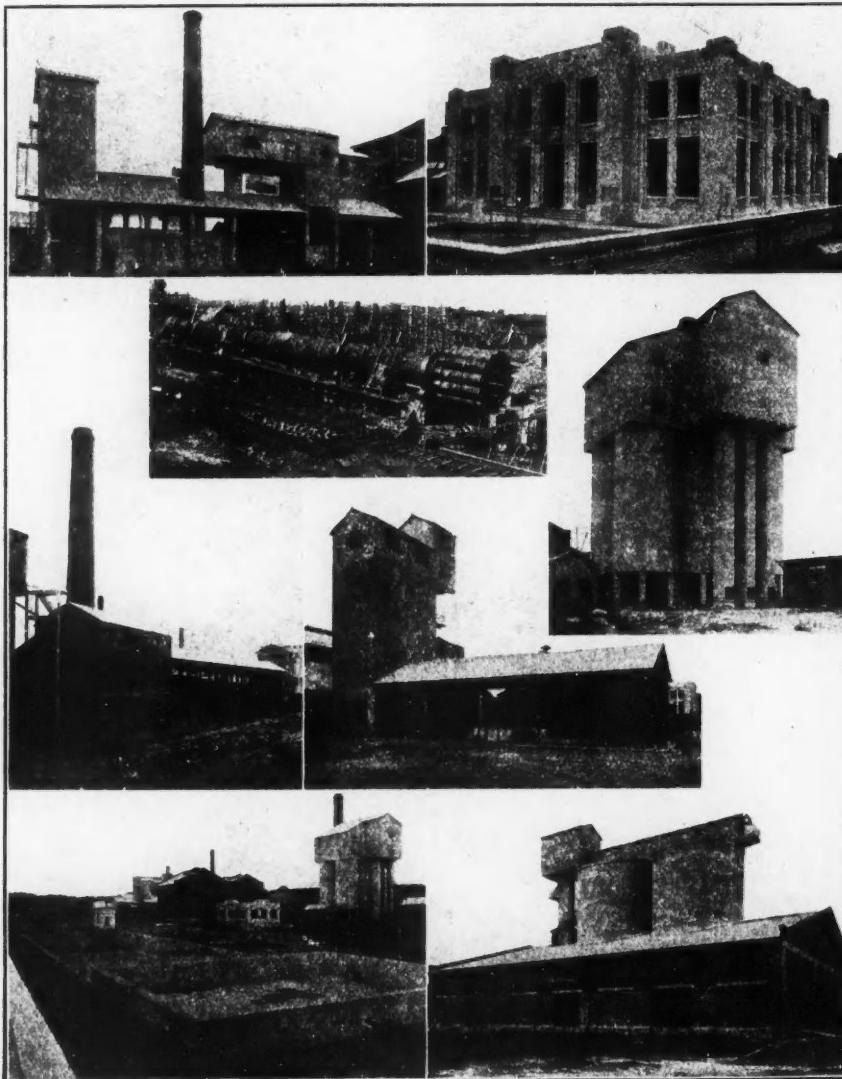
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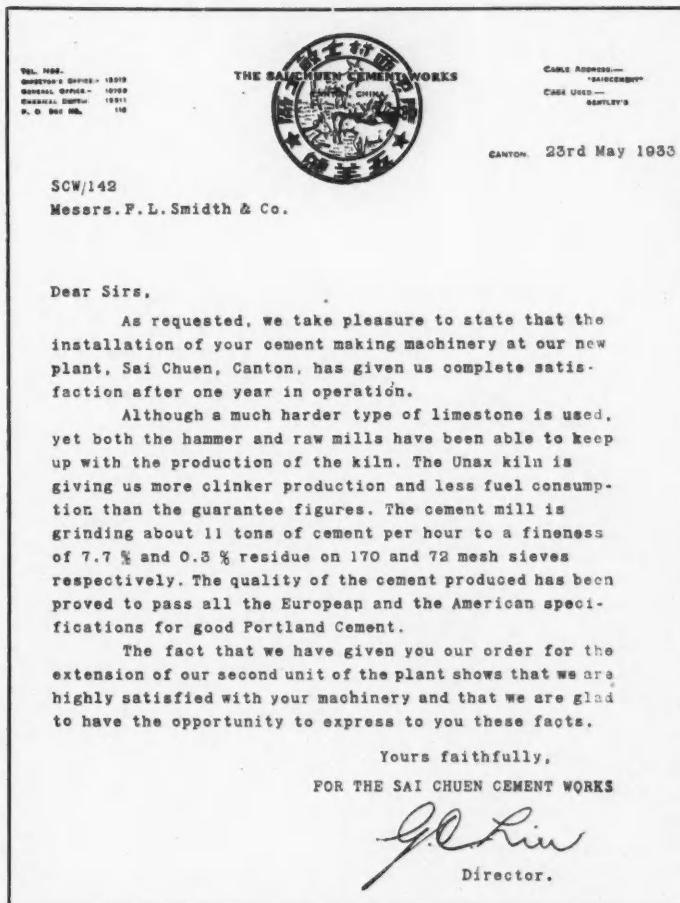




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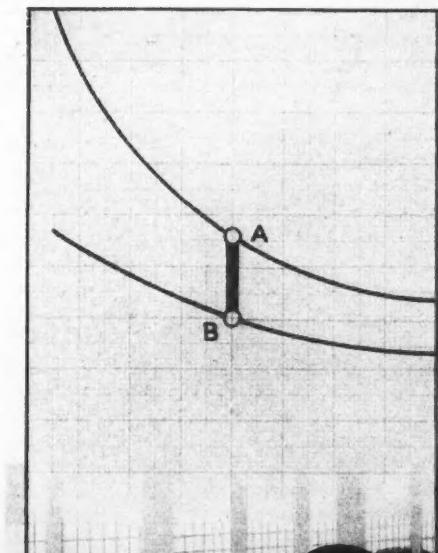
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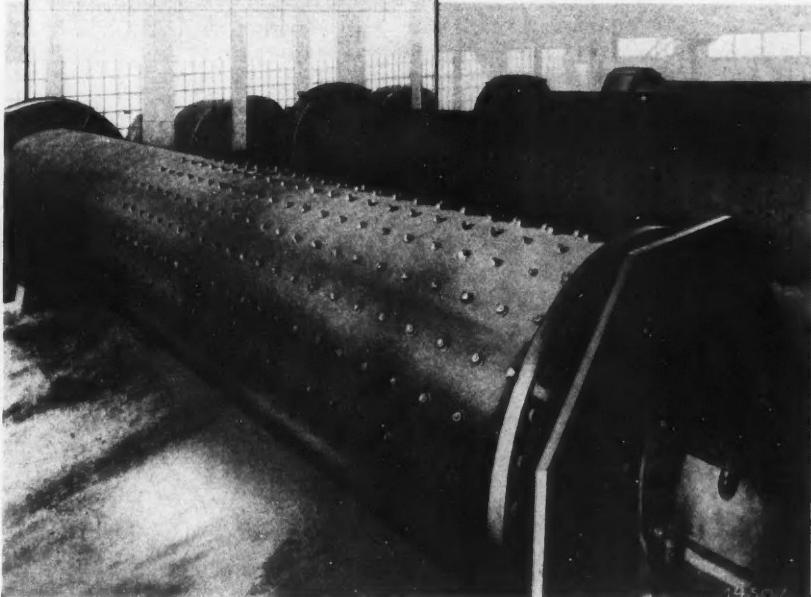




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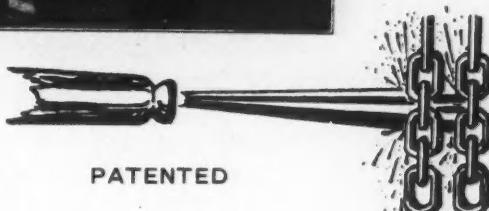
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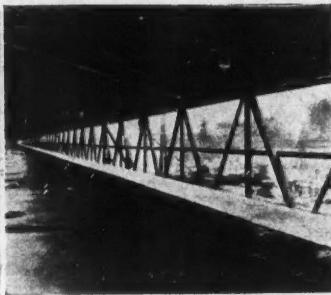
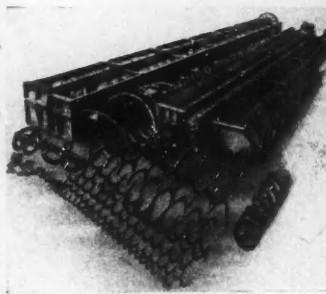
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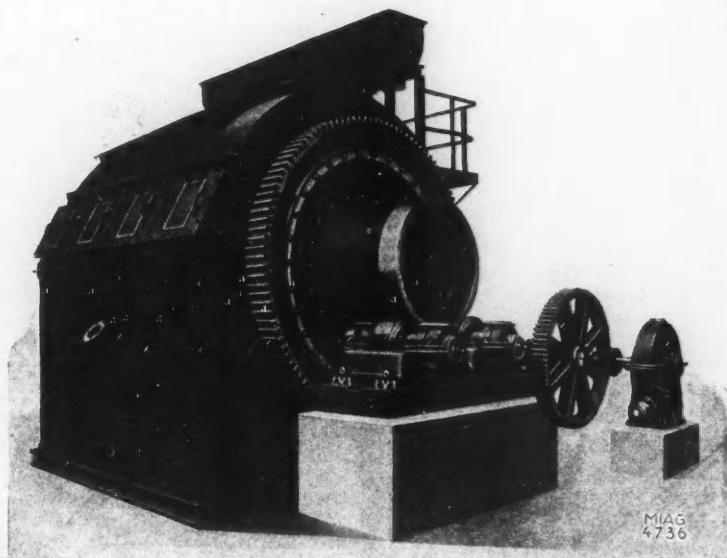
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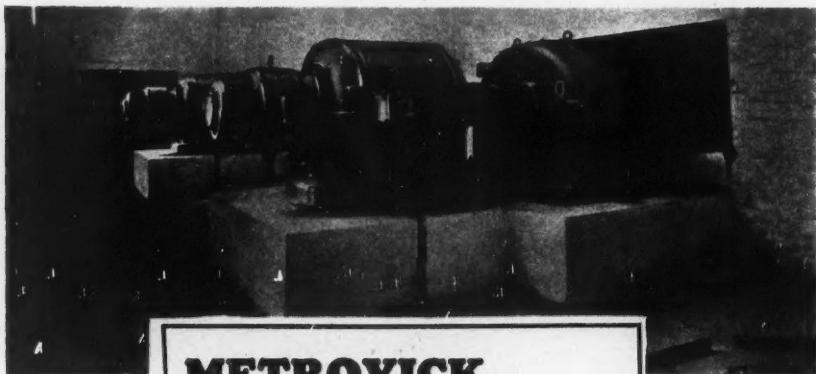
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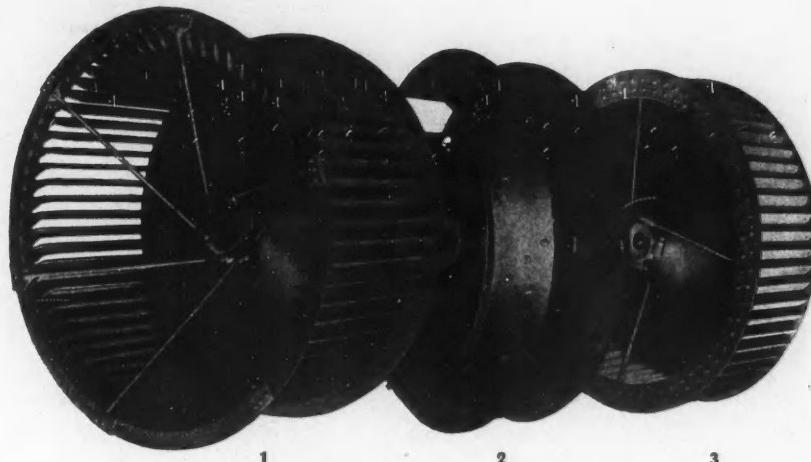
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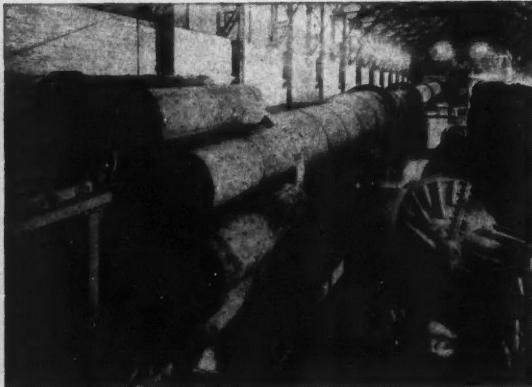
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THE accompanying illustrations shew the completed Works of the Green Island Cement Co., Ltd., Hong Kong, the contract for which was secured by Vickers-Armstrongs Ltd. With a capacity of 2,000 tons per week the plant is now in full production, having successfully passed all the guarantee tests.

*We specialise in the  
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TUBE MILLS,  
DRIERS, CRUSHERS,  
CRUSHING ROLLS,  
MIXERS, AGITATORS,  
ETC.**

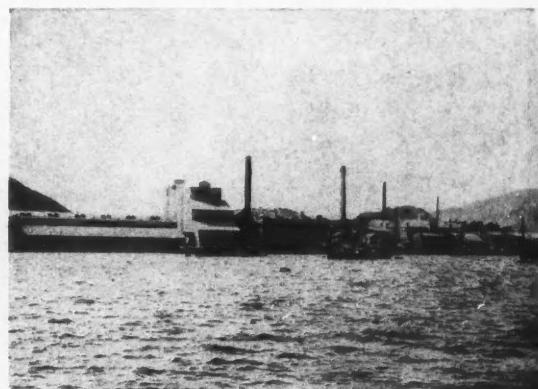
*Illustrations.*

*Top left : Rotary Reflex Kilns,  
7' 9" x 11' 0" x 9' 0" diameter,  
254' 0" long.*

*Bottom left : 3 Compartment Ball  
and Tube Mill for Clinker  
Grinding, 6' 6" x 36' 0" long.*

*Top right : View of Works from  
the sea.*

*Bottom right : View of completed Works.*



*Photographs by courtesy of  
the Green Island Cement Co.*

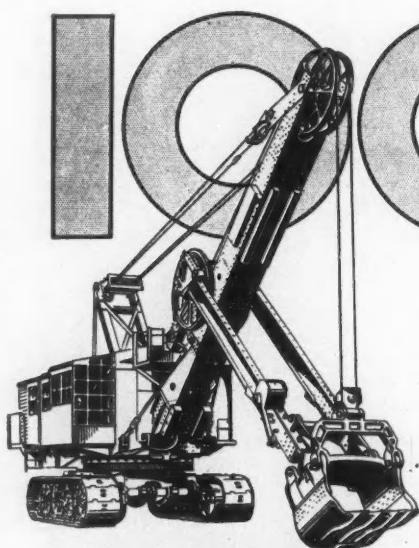
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BUCYRUS**

Registered Trade Mark

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The illustration shows a 100-B working in the cement quarries of Messrs. G. & T. Earle, Ltd., at Hope, England.

Catalogue sent on request.

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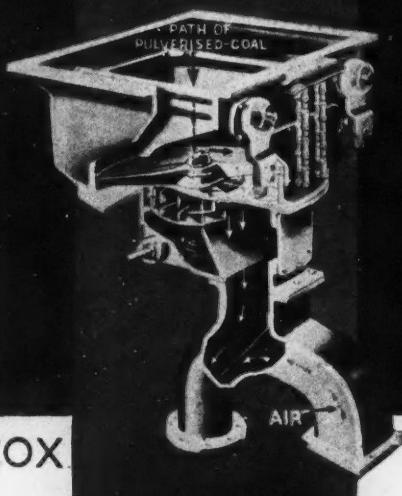
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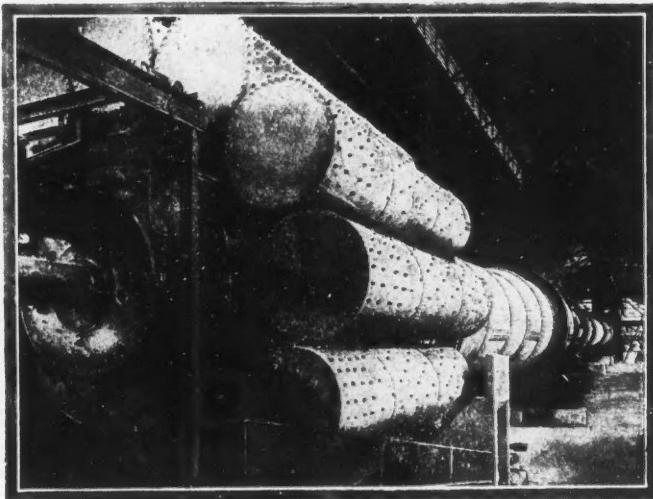
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El grabado reproduce uno de tres grandes hornos rotatorios "REFLEX" provisto de Recuperador patentado, fabricado por los Sres. Vickers-Armstrong, Ltd., de Barrow-in-Furness, Inglaterra. Este horno tiene una longitud total de 99.43 m., siendo el diámetro por encima de los cilindros del recuperador de 8.08 m.

Este tipo de horno hace que los cimientos y edificios puedan ser de una altura mínima, suministrando una economía de inversión de capital y una baja temperatura en los gases de salida, con reducido consumo de carbón.

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# "CEMENT CHEMISTRY IN THEORY AND PRACTICE"

*By Prof. Dr. HANS KÜHL (Director of The Institute for Cement Research, Berlin.)*

## List of Chapters

- I.—The Development of Cement Research.
- II.—The Theory of Cement Burning.
- III.—The Constitution of Portland Cement Clinker.
- IV.—The Problem of Hardening and its Signification in Cement Research.
- V.—The Chemistry of High-Strength Cements.
- VI.—The Technical Aspect of High-Strength Cements.

Dr. Hans Kühl is one of the foremost cement chemists of the world. In this book, which has been translated into English, he exposes the misleading conclusions that have resulted from much of the cement research work of the past, and presents the most up-to-date knowledge on the subject in language readily understandable by the average reader. Dr. Kühl has been an important contributor to the research work on these subjects, some of his work covering a period of twenty years, and this enables him to write as an expert.

As the originator of what may be described as the miniature method of testing described in the book, Dr. Kühl has been the means of connecting the purely scientific work of the laboratory with the manufacturing or technical procedure. Previous investigations have been either the highly-specialised work of physical chemists whereby pure compounds thought to exist in cement have been synthesised and identified by optical constants (but without reference to commercial value as evidenced by strength tests), or the trial-and-error type on the commercial scale which have led to no advance in chemical knowledge. It has been generally admitted that the

latter investigations have led to more fruitful results than the purely scientific work, the production of rapid-hardening cement being a notable example of this. By his technique, however, Dr. Kühl has combined the two methods of investigation, and with no more than three grammes of cement prepared in the laboratory under scientific conditions he is able to apply tests which permit the tensile and compressive strengths of the material to be revealed. Similarly small quantities suffice for setting and soundness tests.

The author exposes the misleading conclusions that have resulted from two conditions prominent in much of the cement research work of the past. The first is the examination of the three-component system (lime-silica-alumina) without due regard to the differences caused by the presence of iron oxide acting as a catalyst or flux, and the second is the common procedure of immersing a few grains of cement in a comparatively large volume of water and assuming that the physical and chemical reactions are similar to those that occur in the practical application of cement when the proportion of water to cement is essentially different.

Two chapters are devoted to the chemistry and manufacture of rapid hardening cement, and more information on this important subject is given than has previously been available to the public. The question is here discussed of the influence of particle size upon strength of cement, and many readers will learn with surprise that there is a limit beyond which fineness of grinding can be continued without advantage to the strength of cement.

Another subject little known to English readers is that of "K.L. storage" of test pieces, i.e. the alternate storage in water and air which constitutes a soundness test and may reveal inherent instability in a cement not detected by the ordinary soundness tests.

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